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6. AUTHOR(S)
Jeffrey R. Koseff

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Dept. of Civil & Environmental Engineering
Stanford University
Stanford, CA 94305-4020

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13. ABSTRACT *(Maximum 200 words)*

The objective of this study was to elucidate ways in which the structure and the motions of olfactory antennae affect how they encounter the concentration distributions in odor plumes. First, detailed measurements, using a combination of laser-Doppler anemometry, laser-induced fluorescence, and planar laser-induced fluorescence were made to characterize the odor plumes for different flow conditions. A model lobster was then placed in the laboratory flume and we measured the odor concentration distribution around the olfactory appendage using high-speed video and laser-induced fluorescence techniques. We found that the plumes are characterized by long filamentous structures which produce concentration fluctuations of hundreds of Hertz. Analysis of the plume data shows that while the peak rms concentration occurs along the centerline of the plume (in the horizontal plane) the peak non-dimensionalized (by the local mean concentration) rms values lie at the edge of the plume. The presence of hairs (versus no hairs) on the lobster antennules greatly influences the duration of time that the odorant is in contact with the antennule during any flicking operation. Flicking has a substantial affect on the redistribution of the odorant on the antennule, and the flicking operation increases the concentration of odorant at the antennule.

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FINAL REPORT

GRANT #: N000149710706

PRINCIPAL INVESTIGATOR: Jeffrey R. Koseff

INSTITUTION: Stanford University

GRANT TITLE: Hydrodynamic Interaction between Olfactory Antennae and Odor Plumes

AWARD PERIOD: 5/15/97 - 09/30/99

OBJECTIVE: The objective of this study was to elucidate ways in which the structure and the motions of olfactory antennae affect how they encounter the concentration distributions in odor plumes. More specifically we wished to determine how the flow micro-environment around olfactory appendages, and the odor-encounter potential of appendages, is affected by (i) the presence and arrangement of sensory hairs, and (ii) the flicking of the appendages.

APPROACH: We collaborated with Mimi Koehl at UC Berkeley on this project to develop odor plumes, in laboratory flow environments, which contain the same characteristics of those found in lobster habitats. The flow conditions were determined from analyses of measurements (made by UC Berkeley) at a variety of coastal habitats. Detailed measurements, using a combination of laser-Doppler anemometry, laser-induced fluorescence, and planar laser-induced fluorescence were made to characterize the odor plumes for different flow conditions. A model lobster was then placed in the laboratory flume and we measured the odor concentration distribution around the olfactory appendage using high-speed video and laser-induced fluorescence techniques.

ACCOMPLISHMENTS:

- We have characterized the plume physics for the flow conditions shown in Table 1. This table also lists the type of data that is available (on request) from each experiment.
- In collaboration with Mimi Koehl at UCB Berkeley we mounted a model lobster and measured (using laser-induced fluorescence techniques with high-speed video) odorant distribution on the antennules for flicking and non-flicking conditions for antennules with and without aesthetac and guard hairs. A typical image (taken from the video sequence) is shown in Figure 1 for an antennule at the end of a downstroke.
- In collaboration with Paul Moore and Mimi Koehl we performed experiments where we inserted an IVEC probe in the lobster antennule (to serve as an aesthetac), and mounted this on the model lobster in the plume. Unfortunately we could not get the IVEC probe to work when it was inserted in the antennule. We do plan to try this again at some later time.
- We have begun to analyze the data from the plume characterization experiments and the model lobster experiments. Some of the analysis from the model lobster experiments is shown in Figure 2.

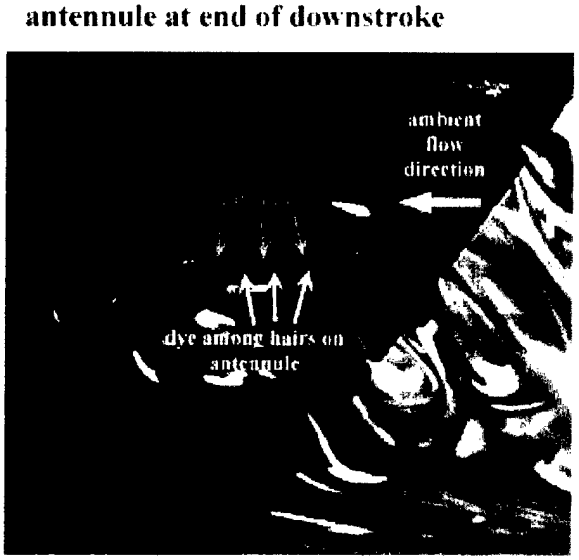

Figure 1: Image taken from video sequence showing antennule at the end of a downstroke in the odorant plume.

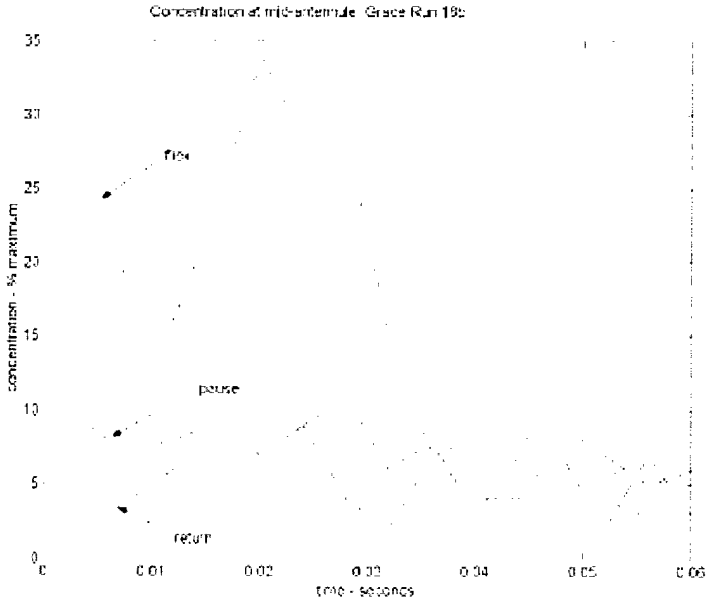

Figure 2: Comparative plot showing the concentration at mid-antennule as a function of time for a downward flick stroke, a stationary antennule, and an upward return stroke. The flicking operation clearly increases the concentration of odorant at the antennule.

Table 1: Record of Plume Experiments

Velocity (cm/s)	Depth (cm)	Width (cm)	Source Type	Roughness	Sheet	X (cm)	Y (cm)	Z (cm)	Long	Movie
10	25.4	60	Flush-Ooze	Smooth	Horiz	40		2	Y	Y
10	25.4	60	Flush-Ooze	Smooth	Horiz	100		2	Y	N
10	25.4	60	Flush-Ooze	Smooth	Horiz	100		4	Y	N
10	25.4	60	Flush-Ooze	Smooth	Horiz	100		0.5	Y	Y
10	25.4	60	Flush-Ooze	Smooth	Horiz	100		0.2	Y	Y
10	25.4	60	Flush-Ooze	Smooth	Trans	40			Y	Y
10	25.4	60	Flush-Ooze	Smooth	Trans	100			Y	Y
10	25.4	60	Flush-Ooze	Smooth	Vert	40	0		Y	Y
10	25.4	60	Flush-Ooze	Smooth	Vert	100	0		Y	Y
10	25.4	60	Flush-Ooze	Smooth	Vert	100	5		Y	Y
10	25.4	60	Flush-Ooze	Smooth	Vert	100	8		Y	N
30	24.4	60	Flush-Ooze	Smooth	Horiz	40		2	Y	N
30	24.4	60	Flush-Ooze	Smooth	Horiz	100		2	Y	N
30	24.4	60	Flush-Ooze	Smooth	Horiz	100		0.5	Y	N
30	24.4	60	Flush-Ooze	Smooth	Vert	40	0		Y	N
30	24.4	60	Flush-Ooze	Smooth	Vert	100	0		Y	N

Notes:

- x: streamwise distance from source (cm)
- y: spanwise distance from source (cm)
- z: vertical distance from source

- "Long" means we took 8000 images at about 2Hz (roughly an hour of data). Each "Long" dataset is anywhere from 5 to 13Gb.
- "Movie" means we took 150 images at 15 Hz (ten second of data). Each movie is anywhere from 100 to 240Mb.
- Note: For both "Long" and "Movie", each image frame covers approximately 15cm x 15cm of the flow, with spatial resolution of 150 microns. The images are 12-bit (4096 grey levels).

C0NCLUSIONS: The plumes are characterized by long filamentous structures which are advected by the mean flow and which produce concentration fluctuations (from an Eulerian viewpoint) of hundreds of Hertz. Analysis of the data shows that while the peak rms concentration occurs along the centerline of the plume (in the horizontal plane) the peak non-dimensionalized (by the local mean concentration) rms values lie at the edge of the plume. This suggests that from a plume-tracking point of view it would be advantageous for an animal to track the "edge" of the plume where the signal-to-noise ratio is the highest. The presence of hairs (versus no hairs) on the lobster antennules greatly influences the duration of time that the odorant is in contact with the antennule during any flicking operation. Flicking has a substantial affect on the redistribution of the odorant on the antennule, and as can be seen in Figure 2 the flicking operation increases the concentration of odorant at the antennule.

SIGNIFICANCE: By determining how the flow microenvironments and odorant encounter of olfactory antennules is affected by their structure and behavior in realistic odor plumes, we are discovering ways in which the physical design of an antenna affects how it filters chemical information from the environment. These basic rules provide insights for the design of man-made chemical sensors and also reveal how other filamentous biological devices work that capture molecules or particles from the surrounding fluid (e.g. gills, filter-feeding appendages).

AWARD INFORMATION: Koseff was appointed the Senior Associate Dean of Engineering as of September 1999.

PUBLICATIONS AND ABSTRACTS:

- Crimaldi, J.P., Wiley, M.B., and Koseff, J.R., " Design and Quantification of a Laboratory Odor Plume for use in Biological Studies of Chemical Sensing and Tracking Algorithms", ASLO Meeting, Santa Fe, New Mexico, , February 1-5, 1999, pp. 51.
- Crimaldi, J.P. and Koseff, J.R., "High-resolution measurements of the spatial and temporal scalar structure of a turbulent plume" submitted to Experiments in Fluids, 2000.
- Crimaldi, J.P., Wiley, M.B., and Koseff, J.R., "The spatial structure of an odor plume emanating from a flush low-momentum source in a turbulent boundary layer", submitted to Physics of Fluids, 2000.
- Koehl, M.M, Koseff,J.R., Crimaldi,J.P, Wiley,M., Cooper,T., Moore,P.A., McCay, M., "Spatial and temporal scales of sampling of odor plumes by flicking crustacean antennules", in preparation, 2000.
- Koehl, M.M, Koseff,J.R., Crimaldi,J.P, Wiley,M., Cooper,T., Moore,P.A., McCay, M., "Flicking lobster antennules physically alter the information in odor plumes", in preparation, 2000.
- Some of the movie clips (described in Table 1) have been included in a NSF-sponsored educational project entitled Multi-Media for Fluid Mechanics. This project will be released in May 2000. The movie clips have been properly attributed to this project.